Chapter 2
Stormwater Hydrology

This Chapter deals with selected topics related to hydrologic modeling practice in Maine. A detailed discussion of hydrologic principles is not included here. Users of this manual should have a working knowledge of applied hydrology, including familiarity with the Rational Method, SCS TR-20 and SCS TR-55 methodology.

Persons without a background in hydrology should refer to the engineering hydrology texts listed in the bibliography. Persons without a working knowledge of the hydrologic principles of stormwater runoff should not be preparing or reviewing the engineering designs for the measures discussed in this document.
This manual is not an exhaustive and detailed design manual for stormwater hydrology information. Information is provided herein to provide a qualified designer with consistent and current data and information to incorporate into a design or analysis.

To assist designers, as well as to provide a standardized database for runoff estimating, selected hydrologic data is provided in this Chapter and in Appendix A. This material includes rainfall intensity duration data and curves, runoff coefficients for the Rational Method, and other data pertinent to Maine and useful in employing the methodologies discussed.

IMPORTANT

Refer to Volume I, Chapter 2 for more information on DEP's four stormwater management objectives, including:

- Effective Pollutant Removal
- Cooling
- Channel Protection
- Flood Control

Chapter Contents:

2.1 Controlling Peak Discharges & Runoff Volumes

The effects of urbanization on runoff are discussed in Volume I, Chapter 1 and Chapter 2. In summary, urbanization increases the volume and rate of runoff from the watershed, which in turn creates higher stream flows during rain events. Higher flows can cause flooding and have adverse effects on natural streams. The stream channel experiences higher flows more frequently and for longer durations. Under natural conditions, a stream experiences bankfull discharge about once every two years, while in moderately developed watersheds, bankfull discharge may occur as frequently as three to four times annually (Schueler, 1987; also see Leopold et. al., 1964 and Andersen, 1970). This may occur even when peak flow rates are controlled because of the increased runoff volume after development. These higher velocity flows cause stream banks to erode and the channel to widen. Eroded sediment is deposited in slower downstream reaches. The frequency of these channel disturbances limits the quality of the habitat in the stream channel, especially for organisms with longer life cycles.

Base flow in streams is also affected by changes in hydrology from urbanization. A large part of base flow is supplied by shallow infiltration. As shallow infiltration is reduced by increased impervious cover, the volume of water available for base flow in streams is reduced. These changes in hydrology, combined with increased pollutant loadings, can have a dramatic effect on the aquatic ecosystem in urban streams.

With regard to urbanization's effects on runoff volumes and peak flows, one goal of stormwater management is to manipulate post development flows to minimize their impacts on downstream (and upstream) capacity and stability. One of the ways to accomplish this objective is to use hydraulic structures to control discharges to approximate original conditions.

To most effectively approximate the original conditions, both the peak discharge rate of runoff as well as the total runoff volume need to be controlled.

Peak rates can be controlled by detention. As shown in Figures 2-1 and 2-2, to effectively control peak rates to pre-development levels, detention structures should be designed with multi-stage discharge structures (such as multiple ori-

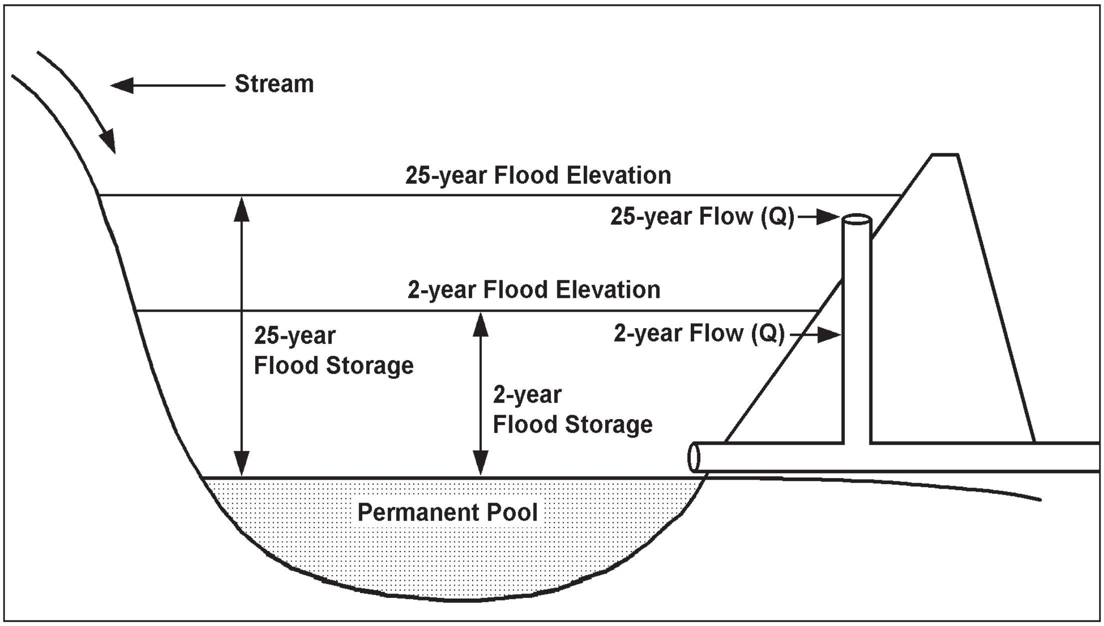

Figure 2-1. Schematic of Multi-Stage Discharge Detention Structure

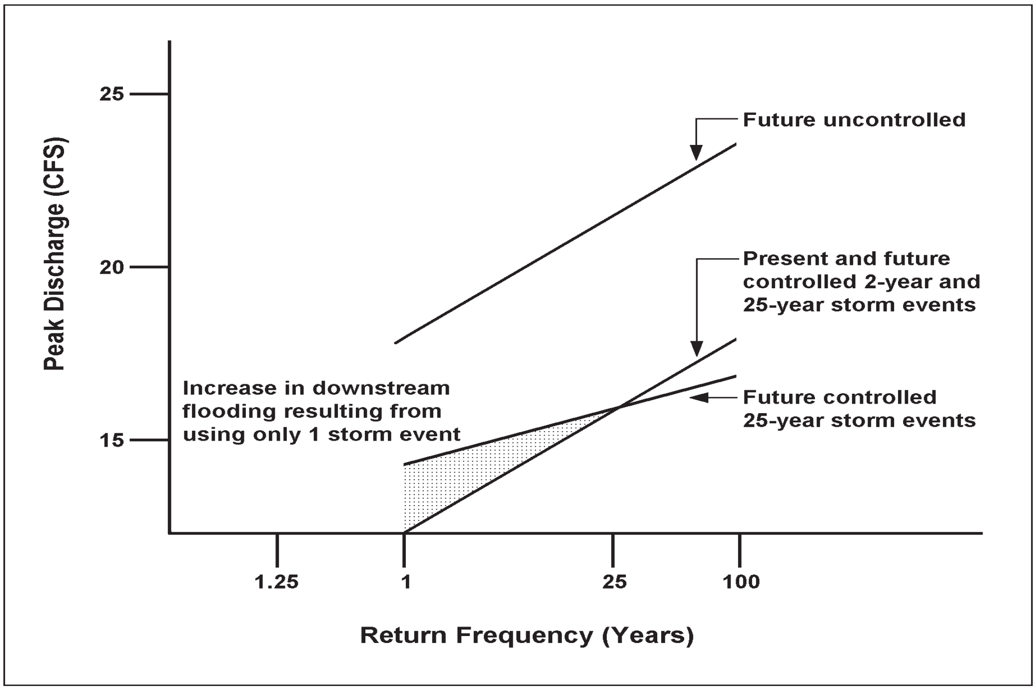

Figure 2-2. Frequency Discharge Curve

fice/weir combinations, or single V-notch weirs) to "bracket" the range of design flows of concern (e.g., 2-year, 10-year, and 25-year frequency events).

Duplicating pre-development runoff volume requires application of infiltration practices. This option is frequently limited or prohibited by site soils constraints and local water quality issues. Thus, where volume reduction is not an option, it is important to incorporate extended detention of the more frequent, potentially channel shaping storms into BMPs to minimize exposure of the stream channel to erosive flows. Schueler (1987, Appendix B of that publication) presents a preliminary methodology for estimating excess storage required to mimic pre-development bankfull flooding frequency.

Other tools available for managing stormwater include grading and channelization practices to lengthen travel times in drainage systems, grading to flatten slopes to increase time of concentration, and downstream modifications to pro vide for capacity and stability to carry increased flows.

2.2 Factors Affecting Runoff

The following material comments on selected factors that affect runoff. It is intended to establish some conventions in the terminology used in this document, and to highlight particular design issues relative to the factors discussed.

1. **Watershed/Drainage Area**: The term watershed is used qualitatively to identify the geographic area of land draining to a stream or other waterbody at a given location. The term catchment is also used. To describe a watershed, one needs to know its area, slopes, drainage characteristics of soils, cover, shape, and hydrography.

   The term drainage area is used to refer to the planimetric dimensions of the watershed. That is, it is a quantitative term, and refers to the measured area of the watershed (e.g., the drainage area of XYZ stream is 381 acres).

Care should be taken when delineating watershed boundaries to show and account for all areas outside the project area that are a part of each watershed.

2. Rainfall: To fully describe a precipitation event, four parameters must be used. They are the amount, the duration, the distribution, and the return frequency. For example, a fully described storm would be: 4.5 inches of rain, of 24 hour duration, having a type III distribution and a return frequency of 10 years.

a. *Rainfall Amounts:* Rainfall is typically recorded in total rainfall received in a 24 hour period. Applicable data for Maine is reported in Table 2-1. Rainfall amounts for shorter time frames are typically recorded by intensity (depth per unit time) and this data is presented in Intensity-Duration curves (as shown in Appendix A).

b. *Storm Duration:* The storm duration is the length of time from the beginning of rainfall to the point when there is no more additional accumulation of precipitation. Storm durations can be quantified in terms of minutes, hours and days, but usually no greater than five days. The duration of a storm is necessary for estimating the rate of runoff discharge. Accurate distributions for actual storms must rely on automatic recording rain gages located at major airports or National Weather Service (NWS) stations.

c. *Rainfall Distribution:* Rainfall intensity is a depth of rainfall per unit of time, usually expressed in inches per hour. Storms will contain many intensities, grouped either randomly (as in a real storm), or in a set sequence (as in a synthetic storm).

Rainfall intensity varies with time during a given storm for different geographical regions and for different locations specific to a region. The Soil Conservation Service (SCS), with the assistance of the National Weather Service, has developed four synthetic 24-hour rainfall time distribution curves for the United States. These include types I, IA, II and III (SCS NEH 4, SCS TR-55) included in Table 2-2. The type II and type III storm distributions as shown in Figure 2-3, are applicable within Maine.

Rainfall is also spatially distributed during a given event. However, for design of most stormwater management facilities, common practice assumes that rainfall is uniformly distributed over the entire contributing watershed. This assumption does not necessarily apply to large, complex watersheds, for which SCS TR-20 or an equivalent model allowing this flexibility should be used.

Table 2-1
24 Hour Duration Rainfalls for Various Return Periods
Natural Resources Conservation Service County Rainfall Data

County	Storm Type	1-Yr	2-Yr	5-Yr	10-Yr	25-Yr	100-Yr	500-Yr	Annual	
		Return Interval or Frequency								
Androscoggin	SEE NOTES 1 AND 2	2.5	3.0	3.9	4.6	5.4	6.5	7.8	45.3	
Aroostook C		2.1	2.1	3.2	3.6	4.2	5.0	5.9	36.1	(Presque Isle Area)
Aroostook N		2.0	2.3	3.0	3.5	4.0	4.8	5.7	36.1	(Fort Kent Area)
Aroostook S		2.2	2.5	3.3	3.8	4.4	5.3	6.4	39.0	(Houlton Area)
Cumberland NW		2.8	3.3	4.3	5.0	5.8	6.9	8.3	43.4	(NW of St. Route 11)
Cumberland SE		2.5	3.0	4.0	4.7	5.5	6.7	8.1	44.4	(SE of St. Route 11)
Franklin		2.4	2.9	3.7	4.2	4.9	5.9	7.0	45.6	
Hancock		2.4	2.7	3.6	4.2	4.9	6.0	7.2	45.2	
Kennebec		2.4	3.0	3.8	4.4	5.1	6.1	7.2	41.7	
Knox-Lincoln		2.5	2.9	3.8	4.4	5.1	6.2	7.4	46.1	
Oxford E		2.5	3.0	4.0	4.6	5.3	6.4	7.6	43.0	(E of St. Route 26)
Oxford W		3.0	3.5	4.5	5.2	6.0	7.1	8.4	43.8	(W of St. Route 26)
Penobscot N		2.2	2.5	3.3	3.8	4.4	5.4	6.4	41.5	(N of Can. -Atl. Rwy)
Penobscot S		2.4	2.7	3.5	4.1	4.8	5.8	6.9	39.5	(S of Can. -Atl. Rwy)
Piscataquis N		2.2	2.5	3.3	3.8	4.4	5.3	6.3	38.5	(N of Can. - Atl. Rwy)
Piscataquis S		2.3	2.6	3.4	4.0	4.6	5.5	6.6	41.0	(S of Can. - Atl. Rwy)
Sagadahoc		2.5	3.0	3.9	4.6	5.4	6.5	7.8	45.3	
Somerset N		2.2	2.5	3.3	3.8	4.4	5.3	6.3	37.3	(N of Can. - Atl. Rwy)
Somerset S		2.4	2.7	3.5	4.1	4.7	5.7	6.8	39.5	(S of Can. - Atl. Rwy)
Waldo		2.5	2.8	3.7	4.3	4.9	6.0	7.1	47.2	
Washington		2.4	2.5	3.4	4.0	4.8	5.9	7.1	44.2	
York		2.5	3.0	4.0	4.6	5.4	6.6	7.8	46.7	

NOTES: REVISED 4/10/92 Lew P. Crosby
24-HR DURATION RAINFALL

SOURCES: 24-HR. DATA - TP 40
ANNUAL DATA - CDAN

Note 1: [1]Use ***Type II*** for Oxford County (with the exception of towns listed below) and Penobscot County (with the exception of towns listed below) and all Main counties not listed below)

Note 2: [2]Use ***Type III*** for York, Cumberland, Androscoggin, Sagadahoc, Kennebec, Waldo, Knox, Piscataquis, Somerset, Franklin, Aroostook, Lincoln, Hancock, Washington Counties; the following Oxford County Towns: Porter, Brownfield, Hiram, Denmark, Oxford, Hebron, Buckfield and Hartford; and the following Penobscot County Towns: Dixmont, Newburgh, Hampden, Bangor, Veazie, Orono, Bradley, Clifton, Eddington, Holden, Brewer, Orrington, Plymouth, Etna, Carmel, Hermon, Glenburn, Old Town, Milford and Greenfield.

Table 2-2
Rainfall Distribution Comparisons for Maine

(DA = Drainage Area)

Numbers refer to percent of total 24 hour precipitation.

Duration	Uniform	Type I For DA >3 sq. mi	Type II[1] For DA <3 sq. mi	Type III[2] For DA <3 sq. mi
6 Min.	0.4%	6.0%	11.25%	8.4%
15 Min.	1.0%	21.0%	38.0%	31.0%
1 Hour	4.2%	28.0%	43.0%	40.0%
2 Hour	8.3%	37.0%	54.0%	50.0%
3 Hour	12.5%	43.0%	58.0%	57.0%
6 Hour	25.0%	57.0%	70.0%	71.0%
12 Hour	50.0%	75.0%	84.0%	86.0%
24 Hour	100.0%	100.0%	100.0%	100.0%

Source: SCS & NWS, NEH-4 and TR-20

d. *Return Period/Frequency:* The return period (sometimes referred to as frequency) of a hydrologic event is the expected (or average) value of the recurrence interval (time between occurrences) of an event equal to or greater than a given magnitude. For example, in Portland, Maine, the return period between storm events with rainfall equal to or greater than 4.7 inches (24-hour storm duration) is 10 years. Alternatively stated, 4.7 inches is the 10-year frequency, 24-hour duration storm for Portland. The probability of a hydrologic event occurring in a given year is the inverse of the return period. Thus, the 10-year frequency storm has a 0.10 probability of being equaled or exceeded in any given year, and the 100-year frequency storm has a 0.01 probability of being equaled or exceeded in any given year. The reader is referred to hydrologic texts from more extensive discussions of frequency analysis (and associated risk analysis).

Note that different types of hydrologic events can have different return periods (or frequencies). For example, the 100-year frequency storm is a rainfall event. The 100-year flood is a peak stage or runoff event. A common assumption of hydrologic estimating methods is that the flood event corresponds with the rainfall event of the same frequency. This is not always true; for instance, a relatively minor storm accompanied by a spring snow melt can result in a relatively major flood event. A flood event may also result from a coastal surge cause by high winds, independent of rainfall.

Severity of a hydrologic event varies inversely with its return period; that is, very severe storms occur less frequently than moderate storm events. The choice of a storm frequency for designing a hydraulic structure can be based on analyzing the risk of damages from storms of greater severity compared to the costs of initial construction.

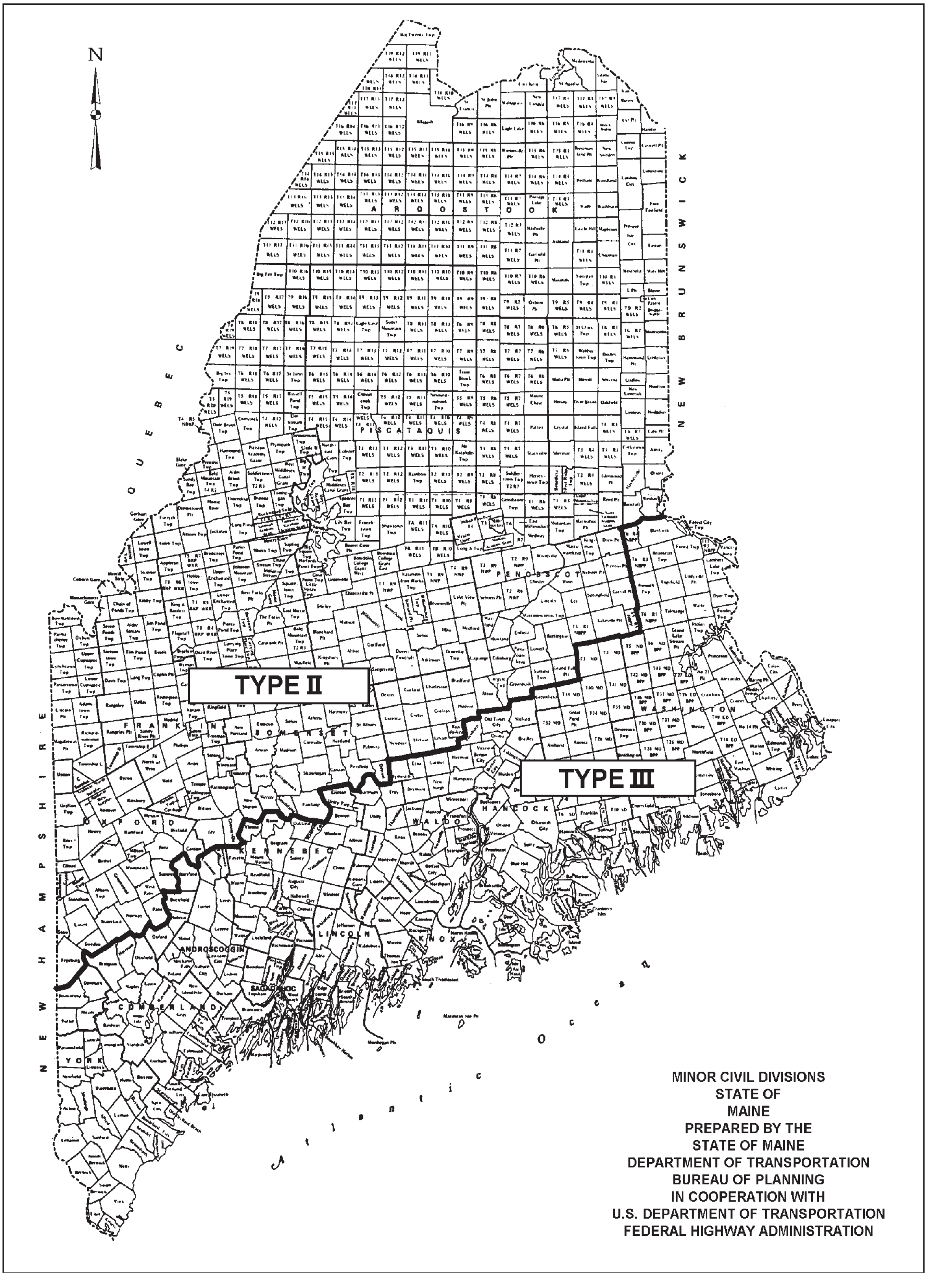

Figure 2-3. Type II and Type III Storm Distributions in Maine

The following is recommended for conventional practice in Maine:

- Piped conveyance systems (storm drains) are designed for the 10-year frequency storm. Culverts under roadways and other major drainage structures are designed for the 25-year storm. The Department of Transportation (DOT) may require design for the 50 or 100-year storm.

- Detention structures are designed to control the 2-year, 10-year, and 25-year frequency discharges. (Ideally, detention structures would control all frequency storms, including "expected" storm events like the 3-month or 6-month storm.)

- Detention structures designed to provide channel protection detention must have principal spillways capable of providing extended detention of 12 hours for runoff from a 2-hour storm of a 1-year frequency.

- Areas that will be inundated during the 25-year frequency storm must be identified and, presumably, suitable for temporary inundation. Structures (residential buildings, public roads, water treatment facilities, etc.) must not be located in areas subject to inundation during a 100-year storm.

- Emergency spillways from detention structures must be designed to independently convey the routed runoff from at least the 25-year, 24-hour storm while maintaining at least one foot of freeboard between the peak storage elevation and the top of the embankment crest. This, in addition to the principal spillway, should provide an adequate margin of safety for conveyance of a 100-year event. A routed 100-year storm is acceptable for other hydrologic methods such as TR-20.

- Designers should note that local ordinances or MEMA/FEMA standards may require sizing of pipes and structures for larger return periods (i.e., less frequent storms).

e. <u>*Rainfall Intensity - Duration - Frequency Relationships:*</u> In designing stormwater management facilities, the designer usually selects one or more "design storms". The most common approach is to use a design storm that relates the rainfall intensity, duration, and frequency (return period). Intensity-duration-frequency (IDF) curves are developed to describe this relationship, based on frequency analyses of rainfall event data at specific locations (some sources publish the data in the form of depth duration frequency maps, e.g., NOAA 35 and TP 40). Rainfall IDF data for Maine has been assembled from a number of sources. This data is included in Appendix A. The designer is referred to the hydrology literature for a more detailed discussion of the derivation of these IDF relationships. The Maine Department of Transportation Highway Design Guide, January 1994 has IDF curves for selected locations in Maine.

3. Soils: Soil characteristics affect the volume and rate of storm runoff. Some hydrologic estimating methods specifically account for soil types (SCS NEH-4, SCS TR-55); others may not (e.g., some references for the runoff coefficient used in the Rational Method do not relate the coefficient to soil type). The choice of a hydrologic model for a specific application may be governed by the extent to which the model accounts for soil conditions.

An extensive description of soil characteristics and relationship to hydrology is not offered here. If a hydrologic model does include a parameter for soil conditions, the following should be considered:

a. <u>*Antecedent Moisture Conditions (AMC):*</u> The SCS models include soils runoff curve numbers based on average antecedent moisture conditions (AMC-II). In some cases, the analysis of dry (AMC-I) or wet (AMC-III) soil conditions prior to the design storm may be warranted. For design purposes, the curve numbers for AMC-II which are built into the models should always be used unless there are specific design criteria specifying otherwise. For analysis purposes where data from TR-20 or other runoff models is being calibrated with actual storm data, an adjustment of the curve number (CN) based on differing mousier conditions (AMC) may be warranted. Any adjustment in CN due to AMC changes must be made with caution and only with proper professional judgement. Tables are provided in Appendix A relative to adjustment based on AMC, and the designer should refer to SCS NEH-4 for guidance on how to apply AMC adjustments.

The definition of each antecedent moisture condition is as follows (SCS NEH-4):

Condition I Soils are dry but not to wilting point; satisfactory cultivation has taken place.

Condition II Average Conditions (Base Values in TR-55 and TR-20).

Condition III Heavy rainfall, or light rainfall and low temperatures, have occurred within the last 5 days; saturated soil.

Table 2-3 gives seasonal rainfall limits for these antecedent moisture conditions.

b. <u>*Hydrologic Soil Group:*</u> The hydrologic soil group (HSG) reflects the infiltration rate of the soil, the permeability of any restrictive layer(s), and the moisture-holding capacity of the soil profile to a depth of 60 inches. The infiltration rate of the soil affects runoff. Generally, the higher the rate of infiltration, the lower the quantity of stormwater runoff.

Table 2-3
Total Five Day Antecedent Rainfall
(inches)

AMC	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 - 1.1	1.4 - 2.1
III	Over 1.1	Over 2.1

Source: Browne, 1990; SCS TP-149

Fine textured soils such as clay produce a greater rate of runoff than coarse grained soils such as sand. The hydrologic soil groups are:

HSG A (Low runoff potential) Soils having a low runoff potential and high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels and having a high rate of water transmission (greater than 0.30 in./hr.).

HSG B Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in./hr.).

HSG C Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission (0.05-0.15 in/hr.)

HSG D (High runoff potential) Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission (less than 0.05 in/hr.)

Source: NEH-4

c. *Changes in Site Soils:* When a site is extensively reworked (i.e., cuts or fills in excess of 60 inches), the hydrologic group associated with the original surficial soils may not apply to the newly graded surface. The designer may need to adjust curve numbers to account for new soils conditions, as well as new cover conditions, to obtain realistic estimates of runoff for this scenario.

d. *Seasonal High Water Table (HWT):* The depth to the groundwater may be determined by the mottles present in the soil horizon. Mottling can be identified from the organic streaking, concretions, and color differentiations or from other morphological features indicative of a seasonal water table. The mottles are caused by the alternation of saturated and unsaturated soil conditions. During saturation, iron and manganese become reduced and exhibit subdued shades of grays, greens or blues. When the soil is unsaturated, the oxygen combines with iron and manganese to develop brighter soil colors such as yellows and reddish browns. Soils that experience seasonally fluctuating water tables usually exhibit alternating streaks, spots or blotches of bright-oxidized colors mixed with reduced dull or subdued colors. The longer a soil is saturated, the greater is the percentage of color that will be subdued.

4. **Surface Cover**: The type of surface or ground cover and its condition also affect runoff volume, as they influence the infiltration rate of the soil. For example:

- Fallow land yields more runoff than forests or grassland for the same soil type.

- Leaf litter and decomposing organic matter maintain the soil's infiltration potential while a bare soil may become sealed by the impact of falling rain. Also, vegetation and foliage retain some of the falling rain and increase the amount evaporated into the atmosphere. Foliage also transpires moisture into the atmosphere and creates a moisture deficiency in the soil which must be replaced by rainfall prior to the occurrence of runoff.

- Vegetation and litter also form barriers along the path of flowing water, decreasing its velocity and reducing the peak rate of runoff. This duff layer also maintains the microtopography of the forest floor.

- Covering areas with impervious surfaces, such as parking areas, reduces infiltration and surface storage, thereby increasing the size of runoff volumes and peak discharges.

5. **Modeling Soil and Cover Types:** When modeling stormwater runoff, a mathematical representation of the combination of soil type and surface cover is often used. In the SCS models (TR-20 and TR-55), the selection of curve numbers (CNs) to represent soil-cover complex types is fairly standardized. For the Rational Method, there are a number of sources offering tables of runoff coefficients ("C"), and the designer has a fair degree of discretion in choosing a value. In order to promote consistency in practice in Maine, this manual recommends that the runoff coefficients used should compare to those published by the ASCE in the most recent manual of practice for stormwater management and as shown in Appendix A. These values should be used for return periods of 2-10 years. Higher values should be used for longer return periods when infiltration and other losses have a smaller effect on runoff. However, alternative methods of determining "C" may be appropriate in some instances (e.g., using methods which yield "C" values corresponding to SCS Curve Numbers).

6. **Time of Concentration and Travel Time:** The Time of Concentration (Tc) is the time required for water to travel from the hydraulically most remote part of the watershed to the point of analysis at the lower end of the watershed. This longest time may or may not be the longest physical distance. Travel Time (Tt) is the time it takes water to travel from one location in the watershed to another. A Tc is determined by summing the Tts along the flow path from the most remote point (time-wise) of a watershed. A Travel Time may be the time water flows from one point to another as sheet flow, shallow concentrated flow, or open channel or conduit flow. A Tc will generally contain a sheet flow component, probably have a shallow concentrated flow component, and may have an open channel or conduit flow component. These components are described as follows:

a. *Sheet flow*: Sheet flow (less than 0.1 foot deep) is flow over a plane surface, which usually occurs in the headwaters of watersheds. With sheet flow, the friction value (Manning's "n") is an effective roughness coefficient that includes the effect of raindrop impacts; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment (SCS, 1986).

Reference is made to SCS Technical Note N4 (SCS, 1986) for limitations as to length of sheet flow. In Maine, the length of sheet flow is seldom greater than 150 feet. A distance of up to a maximum of 300 feet may be possible in a well maintained, slightly sloped paved parking area or a slightly sloped grassed lawn. An on-site inspection (preferably during a runoff event) is the only way to validate the length of sheet flow.

b. *Shallow Concentrated Flow:* After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. In practice, sheet flow probably becomes shallow concentrated flow after a much shorter distance. The point at which shallow concentrated flow occurs should be justified on the basis of a site inspection (for existing conditions), or design grades (for proposed conditions).

c. *Open Channel or Non-pressure Conduit Flow:* Open channel flow may be assumed where channels are visible on aerial photographs or where blue lines (indicating streams) appear on USGS quadrangle sheets. However, the beginning point of the channels is often much higher in the watershed and its location should be verified by an actual site inspection or by survey data. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation. Conduit flow Tts are used only if the discharge is fully contained in the conduit under non-pressure flow. Pipes flowing under pressure cannot be modeled as conduit flow.

2.3 Factors Affecting Runoff

The selection and design of stormwater management practices requires estimates of flow volumes, peak discharges, and detention storage requirements. For some projects, not only must the outlet of a particular watershed be examined but also the downstream effects of changes at the site must be evaluated. A number of methods are available to model hydrologic parameters. These methods are discussed in the following pages, and Data Sheets describing several methods are presented in Appendix B.

A number of public domain and proprietary computer programs are now available, which incorporate one or more of the methodologies discussed here. Appendix C contains brief descriptions of a number of these programs.

2.3.1 Water Quality Volume

The water quality volume is that initial volume (depth) of runoff that is considered to carry the bulk of pollutants deposited since the last runoff event. This is generally defined as a given depth of runoff distributed over the watershed.

Studies have indicated that the first one-inch of runoff carries 90% of the pollution load from a storm. Other research has shown that smaller precipitation events between 0.5 and 1.5 inches of rainfall (approximately the runoff resulting from a 1-year, 24-hour storm event) are responsible for about 75% of the runoff pollutant discharges; larger rainfall amounts (i.e., a 10-year storm event) are associated with drainage design and are responsible for only small portions of annual pollutant discharges (Pitt, 1994). This latter research concludes that treating the initial amount of runoff is effective not because of the first flush, but because the first 0.5 inch of runoff from all storms accounts for almost all of the total annual runoff from most land uses.

It is important to note that the above is only valid for areas with existing impervious area. Developing sites with exposed soils have a high potential for erosion when under construction during larger storms.

Several of the water quality Best Management Practices outlined in Volume III are designed to treat the water quality volume of stormwater runoff and their design should be based on the above criteria.

WATER QUALITY VOLUME DESIGN CRITERIA FOR STORMWATER MANAGEMENT TREATMENT SYSTEMS:

Stormwater management facilities must be designed to treat the first 1 inch of runoff from impervious surfaces and 0.4 inch from landscaped areas.

2.3.2 Runoff Volume and Peak Rate (Single Event)

Many different methods of computing peak rates and volumes of runoff for storm events have been developed. Common methods used in Maine are listed below, with a short description of limitations. Table 2-4 summarizes the recommended applications of these methods. (Adapted from MPCA, 1989):

1. **Rational Method:** The Rational Method establishes an empirical formula that is commonly used in urban areas for computing peak rates of runoff for designing drainage structures. It is useful in estimating runoff on relatively small areas such as roof tops and parking lots. Use of the rational equation should be limited to drainage areas less than 20 acres (Amer. Public Works Assn., 1974) with generally uniform cover type and grade. However, some practitioners dislike using the Rational Method even on the smallest of drainage areas. The most serious drawback of the Rational Method is that it gives only the peak discharge and provides no information about the time distribution of the storm runoff so is therefore not usable for simulation modeling. Furthermore, selecting variables for the Rational Method is more an art of judgment than a precise account of the antecedent moisture condition or an aerial distribution of rainfall intensity (USEPA, 1976). Modifications of the Rational Method have similar limitations (Amer. Public Works Assn. 1974).

2. **TR-20:** The SCS TR-20 computer program is a full hydrographic routing model which uses hydrologic soil cover complexes (runoff curve numbers) to determine runoff volumes as well as unit hydrographs to determine peak rates of discharge. Factors included in the method are 24 hour rainfall amount, a specific rainfall distribution, runoff curve numbers, time of concentration, travel time and drainage area. This method divides the watershed into subareas, completes an outflow hydrograph for each, and then combines

Table 2-4
Selection Criteria for Runoff Calculation Methods
(MPCA, 1989 and modified by Maine DEP)

Output Requirements	Drainage Area	Appropriate Method
Peak discharge only	Up to 20 acres	1 2 4 5
	Up to 2000 acres	2 3 4 5
	Up to 20 sq. miles	2 3
Peak discharge and runoff volume	Up to 2000 acres	2 3 4 5
	Up to 20 sq. miles	2 3
Runoff hydrograph	Up to 20 sq. miles	2 3

1. Rational Method
2. SCS TR-20 Method
3. COE HEC-1 Method
4. SCS TR-55 Tabular Method
5. SCS TR-55 Graphical Method

and routes each subarea to the outlet. It is especially useful for measuring the effects of changed land use in part of a watershed. It can also be used to determine the effects of structures and combinations of structures, including channel modification, at different locations in a watershed. This procedure should be used with caution for drainage areas less than 50 acres or individual drainage areas more than 20 square miles. It may be used on watersheds up to 391 square miles in area, assuming subdivision of the total watershed into relatively homogeneous sub-watersheds of less than 20 square miles each, and routing through all subareas to the study point. It is very useful for large drainage basins, especially when there are a series of structures or detention basins and several tributaries are to be studied.

3. **HEC-1:** The United States Army Corps of Engineers method, HEC-1, provides an evaluation similar to SCS TR-20. Like TR-20, it can be used on both simple and complex watersheds. HEC-1 requires the input of more complex data than TR-20, but provides greater flexibility in calibrating a rainfall-runoff model with actual stream gauge records. A disadvantage could exist in small rugged watersheds where actual runoff documentation is not available. In an area where all soils have been mapped by SCS, the SCS runoff curve number method may offer more accurate results.

4. **TR-55 Tabular Method:** The SCS TR-55 Tabular Method is an approximation of the more detailed SCS TR-20 method. The Tabular Method divides the watershed into subareas, completes an outflow hydrograph for each, and then combines and routes each subarea to the outlet. It is especially useful for measuring the effects of changed land use in a part of a watershed. It can also be used to approximate the effects of a single structure, including channel modification, at the bottom of a watershed. The Tabular Method should not be used when large changes in the curve number occur among subareas within a watershed and when runoff volumes are less than about 1.5 inches for curve numbers less than 60. This method should also not be used if there is a considerable amount of natural detention within or above the study watershed. For most watershed conditions, however, this procedure is adequate to determine the effects of urbanization on peak rates of discharge for subareas up to approximately 2000 acres in size.

5. **TR-55 Graphical Method:** The SCS TR-55 Graphical Method calculates peak discharge and runoff volumes using an assumed unit hydrograph and a thorough, but rapid, evaluation of the soils, slope, and surface cover characteristics of the contributing watershed. This method is recommended for use in the design of erosion and sediment control measures. When more detail and accuracy are required or when an accurate simulation of natural conditions is required, one of the other appropriate methods should be used.

The methods identified in the foregoing discussion (particularly, the Rational method, SCS TR-20 and SCS TR-55 methods) are widely used in Maine for site development related analyses. Other estimation methods are available, and may be useful for particular applications or to cross check results. For example, the Maine Department of Transportation has developed a Highway Design Guide (MDOT, 1990) which prescribes the use of five methods for estimating peak discharges (including the Rational Method). These methods and the limits of their applicability are listed in Table 2-5. The reader should refer to Chapter 12 of the Highway Design Guide and selected references for a further description of the alternative methods. The Maine Geologic Survey also utilizes several methods for large drainage areas (over five square miles) which are typically used to quantify stream flows.

To assist the designer in selection and application of methods for estimating runoff and peak discharge, "Data Sheets" on selected methods are provided in Appendix B. However, the designer should consult the primary references for these methods as well as the applicable reviewing authority prior to final selection and application to a particular project.

Table 2-5
Maine Department of Transportation
Application of Hydrologic Methods for Peak Flow

Method	Drainage Area*	Slope*	Note No.
Potters	>10 acres	N/A	1
BPR 1021	1 to 1000 acres	N/A	1
Bensons	>10 acres	50’-150’/mi	1
Rational	0 to 200 acres	N/A	2
USGS	>100 acres	2’-300’/mi	1

** Do not use a hydrologic method outside of the parameters indicated.*

NOTES:

1. The methods indicated apply to Urban areas only when the discharge originates outside the built up portion of an Urban area, such as a brook whose drainage originates in a Rural area but passes through an Urban area. They do not apply when drainage originates within the built up portion of an Urban area.

2. The Rational Method is a primary tool for use in determining discharge from areas within an Urban area but also will have limited use in Rural areas.

2.3.3 Frequency vs. Discharge Analysis

The before and after runoff analysis is normally depicted graphically with hydrographs. But a plot on log probability paper helps in ease of comprehension and error checking. As shown in Figure 2-2, you observe a lower line representing the pre-condition frequency discharge behavior of the subject watershed. The post condition frequency discharge behavior is shown above. The difference in the peak discharges between the two lines is the increase in flooding. This type of plot shows the reason and need for controlling a "family" of storms to mimic predevelopment conditions.

Flood control is simply the addition of sufficient storage behind a detention pond that lowers the upper line to the lower line. At least one small storm frequency (usually the 2-yr.) and one large storm frequency (usually the 25-yr.) is sufficient to approximate the range of runoff values, although an intermediate storm (such as the 10-yr.) provides a more complete hydrologic model.

The frequency discharge analysis for the before (pre) and after (post) condition should be depicted for project areas of vital interest, at the lower project boundary and at restricted downstream areas of potential flood damage.

2.3.4 Flood Routing/Storage Estimating

Flow routing is a procedure for determining the time and magnitude of flow at a downstream point on a watercourse from known or assumed hydrographs at one or more points upstream (Chow, 1988). If the flow is a flood, the procedure is known as flood routing. A number of methods have been developed for routing hydrographs through hydrologic systems. The reader is referred to the basic hydrology references for detailed presentations of the theory and methodologies of routing.

Flood routing is used in some of the runoff estimation methods (SCS TR-20, HEC-1) to obtain peak flows at different points along a water course. Flood routing is also of importance in modeling the effects of ponded areas on the outflow from a watershed, and for the sizing of detention facilities.

SCS TR-55 includes a graphic methodology to determine detention storage requirements using the output of the Graphical and Tabular runoff estimation procedures. This method is based on the investigation of average storage and routing effects of many structures using the Storage Indicator Method of reservoir routing. This method is approximate, and should not be used to perform final design if an error in storage of 25 percent (oversized storage) cannot be tolerated (USDA/SCS, 1986). A routing method should be used to properly size outlet structures designed for multiple storms.

A number of commercially available computer software packages have been developed which incorporate the SCS-TR-20 or HEC-1 procedures, or other routing methods. See Appendix C.

The Modified Rational Method, while not a true routing procedure, can be used for preliminary design of detention storage for watersheds up to 20 or 30 acres.

2.4 Hydrologic Data for Maine

Appendix A presents hydrologic data applicable to Maine. The information is drawn from a number of sources (as cited) and is presented for the convenience of the designer. The designer assumes any responsibility for selection and application of this data for specific projects.

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